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BUSINESS ANALYSIS AND SOLUTIONS REPORT

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Project 0-4381: Develop an Automated System for Updating Pavement Layer Data

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Project conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration, and the Texas Department of Transportation.		
Abstract: Project 0-4381 is intended to develop the appropriate mechanism and the corresponding algorithms that can be used to build an automated relationship between the pavement layer database and other potential source(s) of pavement layer information at TxDOT. This product provides an analysis of the business needs for pavement layer data and the recommendations for statewide implementation of such a system.	**Keywords:** pavement layer data, automated updating, pavement management	**No. of Pages:** 32

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1. Background

Accurate pavement layer data is critical to the effective engineering and management of pavements. The benefits of pavement layer data are self-evident. The pavement layer information can be used to improve the engineering and management of pavement in many ways. Examples of pavement layer data applications include: the structural capacity analysis of pavements, the performance prediction of pavements, and the selection of the best maintenance and rehabilitation strategies. Indeed, pavement layer data plays an important role in almost every step of pavement management systems.

Since the key to maintaining a database populated with accurate and up-to-date pavement layer data is the availability of an automated system for updating pavement layer data, results from this research could have a significant impact on the practice of pavement engineering and management in Texas. Thus, the Automated Updating System developed under Project 0-4381 is expected to be implemented by TxDOT in the near future.

This report provides a detailed business analysis of pavement layer data and recommendations for implementation of the Automated Updating System. The report includes an analysis of the essential data items, how to obtain these data items, recommendations for TxDOT procedural changes, recommended operating policies and procedures of the system, and additional system enhancements. The benefits and implementation requirements of the proposed system are also summarized here.

2. Essential Data Items for Pavement Layer Data

To meet the requirements of the pavement layer database, both the general pavement layer information and the location information of each highway section must be included in the database. To determine the data items essential to the pavement layer database, previous pavement-related databases have been reviewed, and meetings with TxDOT engineers as experts have been held. The data items that are considered to be essential for inclusion in the pavement layer database are described as follows.

2.1 Section Description Data

The general pavement layer data in the pavement layer database is organized according to pavement sections. The section description data describes the location of the pavement section. Therefore, the combined data items in the section description data should be unique to each pavement section so that they can be used to identify the exact location of each particular pavement section. The following is a list of the section description data items that should be included in the pavement layer database.

2.1.1 Control-Section-Job Number (CSJ Number)

Most of the construction plans at TxDOT are organized by the control, section, and job number of a particular project. Control-Section-Job (CSJ) numbers are numbers assigned to all on-system public highways in Texas. The control number is assigned to a stretch of highway that often breaks at a county line, a major highway intersection, a river, or a stream. However, it can also break at any convenient location. The section number is a number within a specific control and is usually assigned sequentially from the beginning of the control number. The job number is the sequential number for any type of construction project (bridge, paving, etc.) that may have ever occurred on that section of highway. Thus, the CSJ number is a unique, identifying nine-digit number of a project done on a pavement section.

2.1.2 District Name

This data item indicates which district is responsible for each construction project. The state of Texas is geographically divided into 25 highway districts. The area of each of the districts is an aggregation of traffic serial zones used in travel demand modeling for analysis and reporting. It should be noted that each district in which the Texas Department of Transportation conducts its primary work activities is managed by a district engineer.

2.1.3 Highway Name

The highway name is composed of two parts, namely the route description and the number. The route description describes the ranking of the route. There are nine possible route descriptions: IH (Interstate Highway), US (US Highway), SH

(State Highway), BI (Business Interstate), BU (Business US Highway), BS (Business State Highway), FM (Farm to Market), BF (Business Farm to Market) and PR (Park Road). The number distinguishes each highway from other highways with the same route description.

2.1.4 Beginning Reference Marker and Ending Reference Marker

The district name and highway name information determines the location of a specific highway. The CSJ number is then used as the location identification. Under this format, a combined control-section number represents each particular section of highway, and a job number reflects the serial number of work performed on the specific section of highway. However, this location reference method does not provide the exact boundaries of each construction project performed on the highway. Therefore, the Texas Reference Marker system, in addition to CSJ number, is used to identify the exact boundaries of construction work performed on a specific highway section. Such boundaries are defined by the beginning reference marker and the ending reference marker of each work activity. It should be noted that the first marker number represents the beginning of the route. It is the same as the nearest grid location that is derived by imposing a grid on the Texas state map. The following marker number is generally increased by 2, sequentially, until the end of the route is reached. In general, the reference marker increment direction is from west to east or from south to north for straight routes and clockwise for circular loops.

2.1.5 Beginning Reference Marker Displacement and Ending Reference Marker Displacement

Because the real construction section or the maintenance section does not exactly match the sections divided by the road reference markers, values for the beginning reference marker displacement and the ending reference marker displacement are needed to indicate the difference in location of section boundaries from the specified beginning and ending reference markers. For example, a beginning reference marker displacement of 0.5 means that the beginning of the construction section is located 0.5 miles away from the nearest reference marker. These reference marker displacements are used in combination with the beginning and ending reference marker signs to identify the actual boundaries of the construction project.

2.1.6 Beginning Reference Marker Sign and Ending Reference Marker Sign

The beginning and ending reference marker signs are the symbols indicating the ascending or descending direction of the displacement from the beginning and ending reference markers to the exact boundaries of the construction project. The positive sign indicates the displacement in ascending direction from the reference marker, while the negative sign indicates the displacement in descending direction from the reference marker.

With these five data items, the location of a pavement section can be fully determined. Table 1 is an example of the location reference data from the pavement layer database.

Table 1 Sample Location Reference Data in the Pavement Layer Database

DISTRICT	CONTROL	SECTION	JOB	HIGHWAY	Beg Ref Marker	Beg Sign	Beg Disp	End Ref Marker	End Sign	End Disp
LAREDO	0412	05	026	SH0163	0396	-	0.629	0398	+	1.847

As the table shows, the highway in the example is a state highway in the Laredo district. The construction project is the project 026, performed on control section 0412-05 of SH0163. This construction work begins at a point 0.629 mile in descending direction from the 0396 marker and ends at a point 1.847 miles away in ascending direction from the 0398 marker.

2.2 Pavement Layer Data

Data items in this category describe the properties and characteristics of each pavement section. Such data items are listed as follows:

- Pavement Surface Thickness
- Base Thickness
- Subgrade Thickness
- Pavement Width

- Pavement Type, such as joint concrete pavement (JCP), flexible asphalt concrete pavement (ACP), continuous reinforced concrete pavement (CRCP), jointed reinforced concrete pavement (JRCP), joint plain concrete pavement (JPCP), prestressed concrete pavement (PCP), etc.
- Material Type of Each Layer
- Construction Year
- Activity Type, such as overlay, new construction, etc.

3. Data Items Available from Construction Plans Produced by GEOPAK

Based on a survey conducted under this research project, a majority of the TxDOT districts are currently using both GEOPAK and MicroStation to develop construction plans. While most of the discussions are focused on construction plans developed with GEOPAK, Section 9 provides a brief discussion of construction plans developed with MicroStation.

A thorough analysis of the GEOPAK design procedure has been conducted in order to determine what kind of pavement layer information is available from the GEOPAK design process and where such information is stored.

It has been found that TxDOT is now accessing GEOPAK dialogs from Project Manager. Project Manager is a GEOPAK tool that associates a project with its respective gpk job number, users, working directories, and project files. It is also an excellent work flow system that records processes run throughout the design of a project. The working directory along with many other settings can be defined within Project Manager. Once Project Manager is set up, all the design files, output files, and input files created during the GEOPAK design process will be kept in the same working directory for each project. As a result, all the essential pavement layer information of each project can be captured from the same location.

A concentrated analysis has been given to the Proposed Cross Sections design process because it is the only design process of GEOPAK in which the pavement layer data are specified. Essential inputs required in this process are existing ground cross-section design files, pattern design files, existing ground profile design files, shape design files, and criteria files. All of these design files are generated in other design processes of GEOPAK, while the criteria files are tools for creating proposed cross-section drawings at the end of this process.

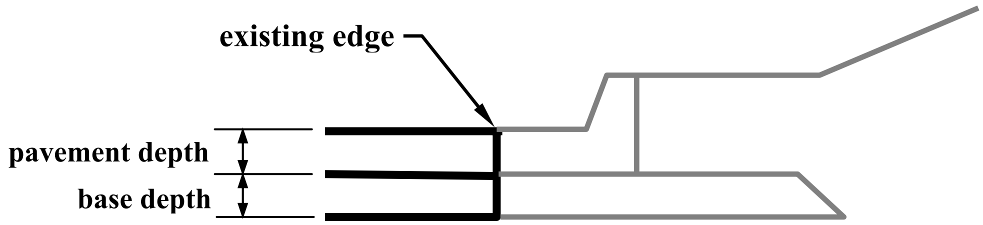
Criteria files are free-format ASCII text files that evaluate conditions that GEOPAK uses to make design decisions. For example, criteria files will check the maximum slope intercept for a ditch section, then select the proper slope to tie to existing ground. Criteria files will consider each cross section individually, making this a very helpful and flexible tool. Criteria files are also used to place structures on the design cross sections, such as curb and gutters, concrete traffic barriers, and retaining walls. Using criteria files, the designer is able to input values for design options (DEFINE Variables) and use MicroStation elements to identify specific design features (DEFINE_DGN Variables). Following are descriptions and examples of elements that may be included in a criteria file.

DEFINE Variables text string keyed in by the user to define a design option, e.g.,
define "BASE DEPTH" 0.5
This defines the proposed depth of a base layer using a value of 0.5 ft.

DEFINE_DGN Variables a series of text strings used to describe a design option or feature stored in a MicroStation graphics file as a MicroStation Element,

e.g.,
```
define_dgn  "ROW" \
dgn = plan.dgn \
lv =17 \
co = 6 \
lc = 0 \
```
This example points to the dgn variable "ROW" and indicates where the feature is referenced in the specified design file by level, color, and line code.

Some of the pavement layer data are also considered as design variables, such as pavement depth, base depth, and so on. An example of how a criteria file works is illustrated in Figure 1. This criteria file is used to place a surface and base layer in the proposed cross-section plans for a rehabilitation job.



DEFINE Variables	**Existing Edge**
	Plan view graphical representation of existing edge
DEFINE_DGN Variables	**Pavement Depth**
	Depth of proposed pavement
	Base Depth
	Depth of proposed base

Figure 1 Example of a Criteria File Used for a Rehabilitation Job [TxDOT 2003b]

At the end of the Proposed Cross Sections design process, an input file, pxsprj.inp, will be generated automatically by GEOPAK in the current working directory. This input file contains all of the essential information required for generating the proposed cross-section drawings, including those pavement layer variables defined in the criteria files. Values for the DEFINE Variables design option are available in the ASCII text format, as illustrated in the following figure.

```
define_dgn "ROW" \
        dgn = D:\GEOPAK\LAREDO\0412-05\026\200110163g.dgn \
        lv = 18 \
        lc = 4 \
        wt = 4 \
        co = 6 \
        type = line, line_string, arc, curve, cmp_string

define_dgn "BASELINE" \
        dgn = D:\GEOPAK\LAREDO\0412-05\026\200110163g.dgn \
        lv = 1,18 \
        lc = 4 \
        wt = 2 \
        co = 0 \
        type = line, line_string, arc, curve, cmp_string

define "SLOPE TEXT SIZE" 0.6

define "ROW BERM DIST" 4

define "BASE DEPTH" 0.5

define "PAVEMENT DEPTH" 0.6

define "SCALE" 2

define "BASE TAPER WIDTH" 0.5

define "FORESLOPE USUAL" 6:-1

define "FORESLOPE WIDTH" 8

define "FILL SLOPE 6" 3:1

define "FORESLOPE MAX" 6:-1
```

Figure 2 Proposed Cross Section Input File Created by GEOPAK

Figure 2 shows that essential pavement layer data, which are pavement depth and base depth, can be obtained from this input file. Base depth of this roadway section is equal to 0.5 ft while pavement surface thickness is 0.6 ft. As a result, the input file generated during the Proposed Cross Sections design process by GEOPAK is the major source of information for the pavement layer database. Moreover, another major source of useful information is the input file generated during the Superelevation design process. Data items that can be extracted from these two input files are listed below:

- Pavement Surface Thickness
- Base Depth
- Subgrade Depth
- Pavement Width
- Construction Year

4. Missing Data Items

Several essential data items, especially section description data, cannot be captured from the input files generated during the GEOPAK design processes. The required pavement layer data that are not currently available within the design processes of GEOPAK are listed below:

- Cross-Section-Job Number (CSJ Number)
- District Name
- Highway Name
- Beginning Reference Marker and Ending Reference Marker
- Beginning Reference Marker Displacement and Ending Reference Marker Displacement
- Beginning Reference Marker Sign and Ending Reference Marker Sign
- Pavement Type
- Material Type of Each Layer
- Activity Type

These missing data items are very important information needed for inclusion in the pavement layer database. As a result, the best procedure for incorporating each of the missing data items into the GEOPAK design processes is carefully determined in order to ensure that those missing data items are automatically and systematically captured by the automated updating system. Such a procedure is described in the next section of this chapter as a recommendation for making those missing data items available to the automated updating system developed under this study.

5. Recommendations for Making the Missing Data Items Available

To capture the missing pavement layer data items stated in the earlier section, a procedure for making those data available to the automated updating system is needed for each of the missing data items. Those procedures are discussed in detail in the following sections.

5.1 Control-Section-Job Number (CSJ Number)

As stated earlier, most of the construction plans at TxDOT are organized by the construction project control, section, and job number (CSJ). The automated updating system will systematically capture the CSJ number if the CSJ number itself is set as the name of the working directory for each GEOPAK design project. It is recommended that the job number be set as the current working directory and the control-section number be set as the name of the parent directory where the working directory is located. An example of this directory hierarchy is as follows.

D:\geopak\LAREDO**0412-05****026**

Where: The control number is 0412
The section number is 05
The job number is 026

5.2 District Name

This data item, which indicates what district is responsible for each particular construction project, should be included in the pavement layer database. In order to capture the district name information, the district name should be set as the parent directory of the Control-Section directory. An example is shown below.

D:\geopak**LAREDO**\0412-05\026

Where: The district name is LAREDO
The control number is 0412
The section number is 05
The job number is 026

5.3 Highway Name

This information will allow easier identification of the location of each construction project. In order to capture this data, the highway name should be set as a project name in Project Manager, which, as stated earlier, is a tool GEOPAK uses to manage all processes run throughout the design of a project. Project Manager associates a project with its respective gpk job number, users, working directories, and project files. After the creation of a new design project, a project file (projectname.prj) will be created in the current working directory. If the highway name is set as the project name within the Project Manager dialog box, the automated updating system will capture the highway name automatically. An example of the project file is shown below.

sh163.prj

Where: The route description is SH (State Highway)
The highway number is163

Figure 3 shows an example of the highway name being set as the project name in the Project Manager dialog box.

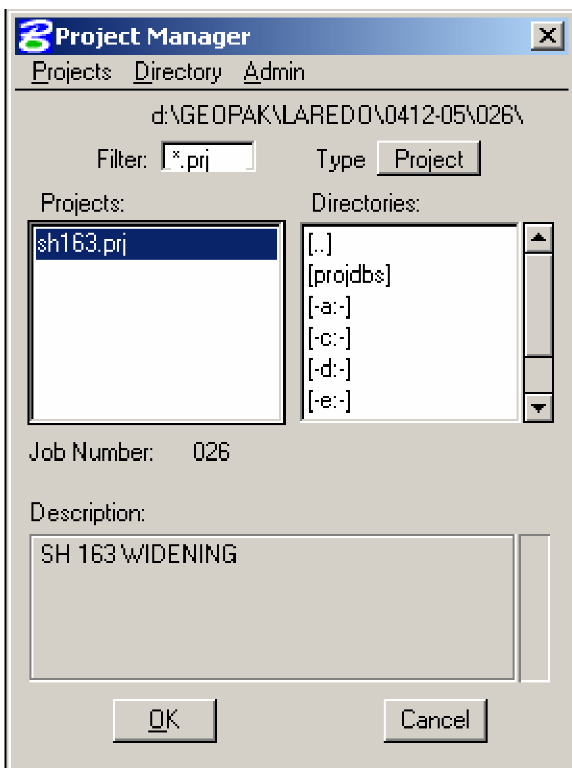


Figure 3 Example of the Highway Name Being Set as the Project Name

5.4 Pavement Type

This is important pavement layer information that must be maintained in the pavement layer database. To make this information available, a dummy criteria file can be created having "PAVEMENT TYPE" as a variable. If this dummy criteria file is added to the Proposed Cross Sections design process, the Pavement Type variable will become an essential input for the design process. Such information will then be available in the input file generated by GEOPAK at the end of the Proposed Cross Sections design process. It should be noted that this dummy criteria file will not have any effect on the proposed cross-section drawings since it does not contain any drawing commands but only the "PAVEMENT TYPE" variable.

5.5 Material Type of Each Layer

Since material type is one of the factors used to evaluate the condition of a pavement structure, material information should be included in the pavement layer database. However, material information is not currently recorded in the GEOPAK design processes performed at TxDOT. Material information can also be made available to the automated updating system using the same procedure as for the Pavement Type information. Adding "BASE MATERIAL" and "SUBGRADE MATERIAL" variables to the dummy criteria file will allow such data to be captured in the input file generated by GEOPAK.

5.6 Beginning Reference Marker, Beginning Reference Marker Sign, and Beginning Reference Marker Displacement

Beginning Reference Marker, Beginning Reference Marker Sign, and Beginning Reference Marker Displacement values represent the beginning boundary of a construction project. Therefore, these three data items should be maintained in the pavement layer database. Without the exact location information, the full benefits of the pavement layer database cannot be achieved. The automated updating system can capture these three data items by adding "BEGINNING REFERENCE MARKER" and "BEGINNING REFERENCE MARKER OFFSET" variables to the dummy criteria file. It is important to note that values for the Beginning Reference Marker Sign and the Beginning Reference Marker Displacement can be combined jointly into the "BEGINNING REFERENCE MARKER OFFSET" variable. The automated updating system is arranged to split the input information into two data items and store them separately in the pavement layer database.

5.7 Ending Reference Marker, Ending Reference Marker Sign, and Ending Reference Marker Displacement

Ending Reference Marker, Ending Reference Sign, and Ending Reference Marker Displacement values represent the ending boundary of a construction project. They can also be made available to the automated updating system using the same procedure as for the beginning boundary of the construction project by adding "ENDING REFERENCE MARKER" and "ENDING REFERENCE MARKER OFFSET" variables to the dummy criteria file.

5.8 Activity Type

Activity type of a project is one of the essential elements of information to be included in the pavement layer database. This data item indicates what activities have been applied to each highway section. To capture this information, the "ACTIVITY" variable is added to the dummy criteria file. With this criteria file, the activity information is obtainable in the input file generated at the end of the Proposed Cross Sections design process.

The dummy criteria file containing variables for all missing pavement layer data, namely layerdata.e, is created and used in the Proposed Cross Sections design process to verify the effectiveness of the proposed procedures for capturing those missing data items. An example of such a dummy criteria file is illustrated in Figure 4.

```
/*-----------------------------------------------------------------------------*/
_s_message1 = ^PAVEMENT TYPE^
_s_message2 = ^BASE MATERIAL^
_s_message3 = ^SUBGRADE MATERIAL^
_s_message4 = ^BEGINNING REFERENCE MARKER^
_s_message5 = ^BEGINNING REFERENCE MARKER OFFSET^
_s_message6 = ^ENDING REFERENCE MARKER^
_s_message7 = ^ENDING REFERENCE MARKER OFFSET^
_s_message8 = ^ACTIVITY^


if pavement slope < 100 then
{
        if _s_message1 = "PAVEMENT TYPE" then
        draw dx = 0 dy = 0
        if _s_message2 = "BASE MATERIAL" then
        draw dx = 0 dy = 0
        if _s_message3 = "SUBGRADE MATERIAL" then
        draw dx = 0 dy = 0
        if _s_message4 = "BEGINNING REFERENCE MARKER" then
        draw dx = 0 dy = 0
        If _s_message5 = "BEGINNING REFERENCE MARKER OFFSET" then
        draw dx = 0 dy = 0
        if _s_message6 = "ENDING REFERENCE MARKER" then
        draw dx = 0 dy = 0
        if _s_message7 = "ENDING REFERENCE MARKER OFFSET" then
        draw dx = 0 dy = 0
        if _s_message8 = "ACTIVITY" then
        draw dx = 0 dy = 0
}
else
{
        if _s_message1 = "PAVEMENT TYPE" then
        draw dx = 0 dy = 0
        if _s_message2 = "BASE MATERIAL" then
        draw dx = 0 dy = 0
        if _s_message3 = "SUBGRADE MATERIAL" then
        draw dx = 0 dy = 0
        if _s_message4 = "BEGINNING REFERENCE MARKER" then
        draw dx = 0 dy = 0
        If _s_message5 = "BEGINNING REFERENCE MARKER OFFSET" then
        draw dx = 0 dy = 0
        if _s_message6 = "ENDING REFERENCE MARKER" then
        draw dx = 0 dy = 0
        if _s_message7 = "ENDING REFERENCE MARKER OFFSET" then
        draw dx = 0 dy = 0
        if _s_message8 = "ACTIVITY" then
        draw dx = 0 dy = 0
}
```

Figure 4 Dummy Criteria File Containing Variables for the Missing Data Items

The dummy criteria file, layerdata.e, is then added to the Shape Clusters definition using the Shape Clusters dialog box during the Proposed Cross Sections design process, as illustrated in Figure 5.

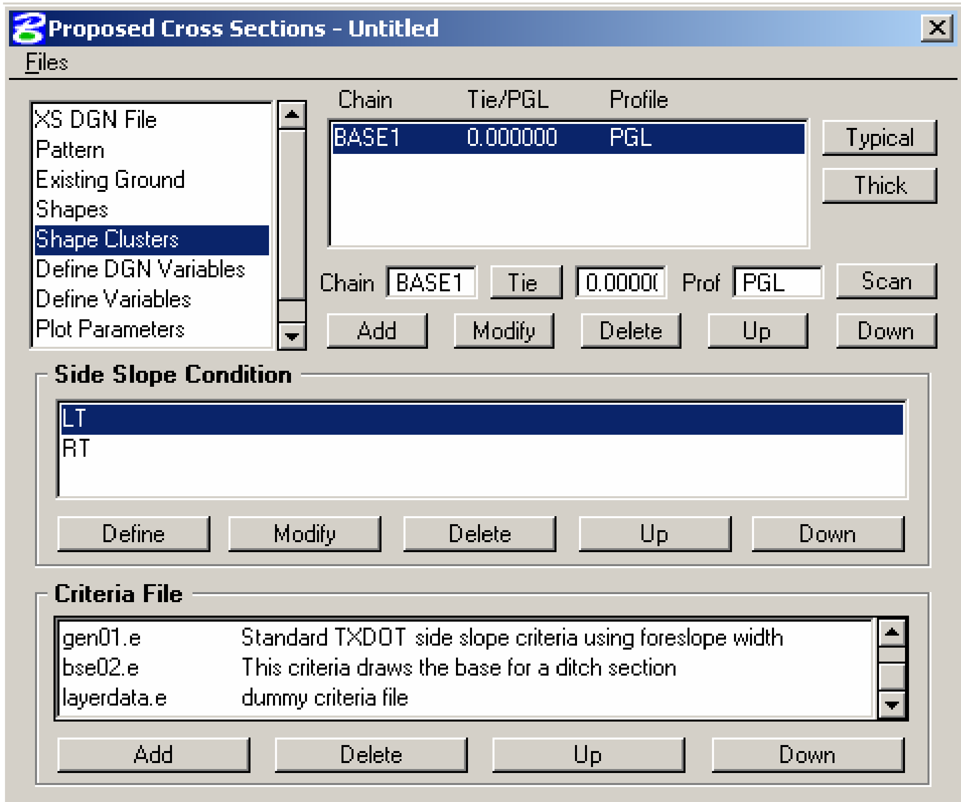


Figure 5 Shape Clusters Dialog Box Displaying layerdata.e Criteria File

Once the dummy criteria file is added to the Shape Clusters definition, the Define Variables dialog box displays the variables for the missing pavement layer data that are now available to be included in the Proposed Cross Sections design process, as depicted in Figure 6.

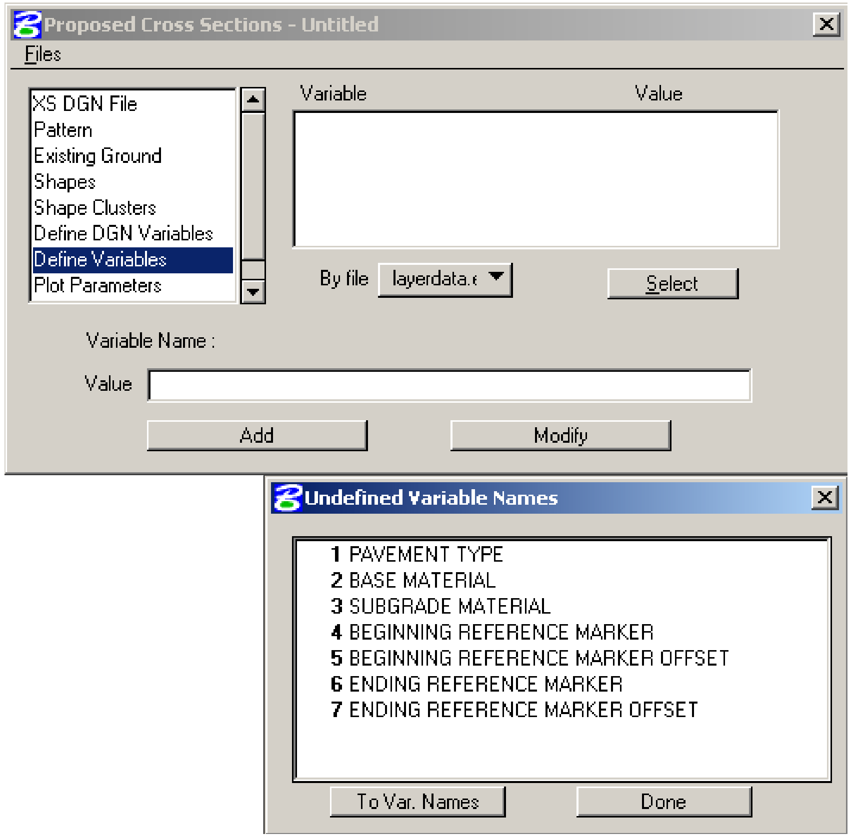


Figure 6 Pavement Layer Variables Defined in layerdata.e

Eventually, the value entered in the Define Variables dialog box for each of the variables along with the variable name are stored in the input file produced by GEOPAK at the end of the Proposed Cross Sections design process. This input file is used by GEOPAK to draw all the cross-section drawings within the specified roadway section.

6. Recommendations for TxDOT Procedural Changes

Since the current practice at TxDOT does not provide full support to the automated updating procedure, some modifications in current GEOPAK design processes are needed to make them compatible with the developed Automated Updating System.

To implement the Automated Updating System application, two important modification issues must be considered: (1) the structure of project directory and (2) the dummy criteria file.

6.1 The Structure of GEOPAK Directory

To achieve full benefits of the Automated Updating System, each of the GEOPAK design projects must be named and organized based on the highway name, the district name, and the CSJ number of each construction project. The following is a list of changes in structure of the GEOPAK project directory needed for Automated Updating System implementation.

1) The name must be set as the name of the GEOPAK design project in the Project Manager dialog box, illustrated in Figure 3.
2) The working directory for each GEOPAK design project is designated by the job number of the construction project.
3) Each GEOPAK design project, identified by the job number as the project name, is a subdirectory within a parent directory named as the control-section number of such construction project.
4) All control-section directories must be kept within the main directory, which uses district name as the name of the directory.
5) Once a GEOPAK design project is completed, it should be moved to a central hard drive where all computers in the network are able to access it.

An example of the structure of a GEOPAK project directory is shown as follows.

D:\geopak\LAREDO\0412-05\026\SH163.prj

Where: The route description is SH (State Highway)
The highway number is 163
The highway name is SH163
The district name is LAREDO
The control number is 0412
The section number is 05
The job number is 026

6.2 The Dummy Criteria File

In general, during the Proposed Cross Sections design process within GEOPAK, the designer is expected to add a set of criteria files in the Shape Cluster dialog box. These criteria files are tools used for creating proposed cross section drawings at the end of this process.

To effectively operate the Automated Updating System, the dummy criteria file created in this study, namely layerdata.e, must be included in the Proposed Cross Sections design process of every design project in addition to the general criteria files, as illustrated in Figure 5. Detailed information on this dummy criteria file can be found in Report 0-4381-1, in Section 3.4 of Chapter 3.

7. Recommended Operating Policies of the Automated Updating System

The recommended operating policies and procedures of the Automated Updating System are listed as follows:

1) The Automated Updating System application should be installed on only one computer that has access to not only the central hard drive used to keep all complete design projects but also all single computers within the network. This is to ensure that the central pavement layer database will contain pavement layer data of all pavement sections presented in the network.

2) Immediately after installation of the automated software, the user is required to go to the Scheduled Tasks utility within the Control Panel and set the Automated Updating System application to be launched in a timely manner so that any change made to the pavement layer structure can be automatically reflected in the pavement layer database.

3) Fundamental provisions should be made available for the primary user (TxDOT District Pavement Engineer) to perform data validation in an efficient manner once the pavement layer data is accepted and then stored in the pavement layer database.

4) The primary user must be an authorized user whose account is allowed to access every hard drive within the network. This is to avoid the inability of the Automated Updating System to access specified hard drives.

8. Recommendations for Enhancements to the Automated System

The Automated Updating System software can automatically capture pavement layer information of any construction or maintenance activity made to a pavement layer structure and systematically update the pavement layer database with the captured information. It also provides a user-friendly graphical user interface (GUI) used not only to store, modify, delete, and display the pavement layer information stored in the output file but also to update the pavement layer database with the captured layer information. Additional improvements can be made to this Automated Updating System software as well as the pavement layer database, taking advantage of both the programming and database technology.

It is recommended that future research address the following issues:

1) The Automated Updating System software displays the pavement layer information and the current layer information of a desired pavement section stored in the pavement layer database only in tabular format. However, in general, one would expect to visualize the layer information in a graphical format as well. It is therefore desirable that the automated software be able to graphically display pavement layer information. In order to have such a capability, another software subroutine must be developed to graphically display the tabular data.

2) Since the current research is intended to focus on the mechanism for an automated system to update the pavement layer database rather than the development of a pavement layer database itself, provisions of the database utilities for validation and correction of the stored layer data are needed. Even though various precautions have been taken under the current Automated Updating System to control the quality of the data through algorithms, the quality of the captured data can only be as good as the quality of the original source. Therefore, it is critical

that the data stored in the pavement layer database can be manually accessed, visualized, validated, and corrected if needed.

3) The current Automated Updating System software shows the pavement layer information of all pavement sections stored in the pavement layer database. However, the user may only need to view the pavement layer information of specific pavement sections falling within required criteria. As a result, a Filter function should be made available to the Automated Updating System in the future development. This function will allow the user to set up display criteria or conditions so that only those pavement sections that satisfy the criteria will be displayed.

4) The Pavement Section at TxDOT has scanned all pavement design files and archived them electronically. The pavement design files are not only a good source for validation of pavement layer data, but also extremely beneficial to a number of daily activities performed by TxDOT district personnel. The integration of such pavement design files with the layer data is therefore of great importance to the pavement layer database and the district-level end users of the pavement layer data. A mechanism for such integration should be explored and developed.

5) The Automated Updating System software is a stand-alone system that runs on a single computer. To capture pavement layer information and update the pavement layer database with the captured changes, the users must locally access a particular computer that has the automated software installed. However, to fully achieve a live and accurate pavement layer database, the Automated Updating System software should be able to handle all of the computers in the network that are used to save design projects produced by GEOPAK. As a result, in a future study, efforts should be made to enhance the current Automated Updating System software so that it can be operated in the Internet environment, where authorized users can access the automated software interface through a Web browser.

6) The pavement layer database is a relational database. All the data items in the database are in standard data formats such as integer, double, or string. But in reality, the users may need to attach objects such as photographs of the road conditions taken in the field to the pavement layer database. It is desirable that the pavement layer database be able to handle objects in addition to the tabular data. In order to have such a capability, the automated software must be upgraded to an object-relational database that combines both relational technology and object-oriented technology. Since the technology for an object-relational database is not well developed yet, it is not feasible to apply it in this study. With rapid development of database technology, however, this concept may become more realistic in the near future.

9. Recommendations for Construction Plans Developed with MicroStation

However, it is important to note that the required pavement layer information available in the design files (.DGN) is stored in binary format; thus, those design files must be decoded in order to get the specific information from the construction plans. In addition, as stated earlier, the design files are sequential, variable-length files with variable length records; this means that the order of elements in a design file does not depend on the graphical location of such elements, but rather on the sequence in which such elements were added to the design file. These drawbacks lead to a significant complexity in developing a system to track and capture the required pavement layer data stored in binary format from the design files.

In order for TxDOT to extract layer data from construction plans developed with MicroStation, two approaches are recommended:

1) It is recommended that a simple table for layer data input be developed and included as part of the process of developing construction plans with MicroStation. The layer information in the table can then be used to update the pavement layer database. This approach is similar to the "criteria file" approach used for GEOPAK that has been pilot-tested.

2) As an alternative approach, it is recommended that an algorithm based on optical character recognition (OCR) technology be developed to extract layer data from the .DGN files. However, because of the nature of .DGN files, the OCR process would be cumbersome and time-consuming. Developing such an OCR-based algorithm would also pose potential challenges.

10. Benefits of the Automated Updating System

The following is a list of the potential benefits of the proposed Automated Updating System:

- Minimizes the manual effort required to keep the pavement layer data updated.
- Minimizes the disruption to the current practice since the developed system is consistent with the current GEOPAK design practice at TxDOT.
- Minimizes the extra work of the districts because the Automated Updating System software is being developed in such a way that any changes made to the pavement layer structure can be automatically reflected in the pavement layer database without any efforts required from TxDOT division and district offices.
- Maximizes the quality of pavement layer information since both data extraction and data updating processes are automatic.
- Significantly reduces the resources needed to maintain the database because of the automatic nature of the developed system.
- Decreases the risk of poor decisions due to incomplete pavement layer data because the Automated Updating System provides all essential pavement layer information required for various pavement management activities.
- Provides easy access to information through the user-friendly Graphical User Interface (GUI) of the Automated Updating System.
- Provides more up-to-date information as the system is intended to automatically capture the layer information from the input files produced by GEOPAK and systematically update the pavement layer database whenever needed.

- Reduces manual errors since the manual effort of maintaining the pavement layer database is minimized.
- Prevents duplication of pavement layer data recording due to the characteristics of the system described in Report 4381-1, Section 4.3 of Chapter 4.
- Provides a systematic procedure for updating the pavement layer database.